EFFECTS OF AGEING ON GAIT COMPLEXITY

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Ageing alters gait patterns that influences the control mechanism of human movement. The aim of this study was to identify the age-related differences in complexity of gait kinematics. Gait is a fundamental but complex action, and loss of complexity has been suggested with ageing. In this study multiscale entropy (MSE) analysis was used to investigate complexity in gait. Whole body kinematic data for 10 younger adults (21±1.84 years old) and 10 older adults (62.7±2.2 years old) running at 9 km/h on the treadmill for 2 minutes were analysed. Body centre of mass (CoM) were calculated. MSE of CoM position, and ankle, knee and hip angles were estimated. Hip angular displacement exhibited higher MSE (higher complexity) compared to the CoM position, ankle and knee angular displacement. MSE increased from ankle to knee to hip. MSE of the Hip was significantly lower for the older compared to the younger group, but MSE was not different between young and old participants for other variables. Loss of complexity may only be observed for some kinematic variables, which is a key point to consider for future work applying these techniques to understand gait changes with age.

KEYWORDS: nonlinear dynamic analysis, multiscale entropy, motor control.

INTRODUCTION: Kinematic characteristics of gait have been shown to have lower complexity in older compared to younger adults (Bizovska et al., 2018; Dingwell & Cusumano, 2000; Stergiou, 2016). Lower complexity indicates lesser flexibility and adaptability (Santinelli et al., 2019). Thus, lower complexity in older adults, increases the risk of falling (Bizovska et al., 2018). Traditional biomechanics tools cannot capture complexity of gait (Bizovska et al., 2018). As a response to this problem, nonlinear dynamic measurements have been used (Bizovska et al., 2018; Dingwell & Cusumano, 2000; Stergiou, 2016). Specifically, measures of entropy can capture complexity and quantify the regularity or predictability of gait (Bisi, Riva, & Stagni, 2014; Buzzi, Stergiou, Kurz, Hageman, & Heidel, 2003). There are different types of entropy, such as single-scale entropy analysis, approximate and sample entropy (SE), multiscale entropy (MSE) and refined multiscale entropy. Among all the entropy measurements, it is suggested that MSE can capture better complexity of gait (Yentes & Raffalt, 2021) .
In the literature, MSE has been calculated for a variety of kinematic variables such as marker position, joint angular displacement and velocity, and acceleration (Bizovska et al., 2018; Bizovska, Svoboda, Vuillerme, & Janura, 2017; Karmakar, Khandoker, Begg, Palaniswami, & Taylor, 2007). In fall risk assessment studies, trunk acceleration was mostly used (Bizovska et al., 2017). For MSE estimation the selection of input parameters of tolerance window r, vector length m, time series length N and number of scales should be based on the research question which suggests that there are no fixed recommended values (Yentes & Raffalt, 2021). Considering the diverse kinematic variables analysed as well as the variation in input parameters, it is difficult to directly compare MSE results across studies. In this study, MSE was calculated for three different positions to investigate which of them can better capture complexity of gait in younger and older populations. In addition, effects of fixed input parameters (r, m, N and number of scales) on the MSE estimation have been investigated. In this study, it is hypothesized that MSE of all different kinematic positions is lower in older adults compared to the younger adults.

METHODS: Ethical approval was obtained from the University of Exeter ethics committee (ref. 180613/A/02). Position data, previously reported by Kwek and Williams (2021), were reanalysed in the present study. Ten younger adults (18-24 y/o) and 10 older adults (59-65 y/o) participated (Table 1) in this study. Participants were selected based on the following criteria: no musculoskeletal, cardiorespiratory, neurological, or other chronic disorders; no known problems in daily activity; recreational runners, minimally half an hour, twice a week; no use of orthotics that could alter gait.

Table 1: Descriptive characteristics of participants.

	Mean (sd)	
	Younger adults	Older adults
Sex (male/ female)	4/ 6	5/ 5
Age (years)	21 (1.84)	62 (2.2)
Height (cm)	166.72 (7.8)	170.54 (7.31)
Weight (kg)	61.72 (7.8)	68.6 (11.28)

Trials were conducted on a treadmill (Taurus T10.5 Pro treadmill, Taurus Fitness Sport-Tiedje GmbH, Germany) at a steady running speed of 9 km/h, for two minutes. Whole-body marker trajectories were recorded at 200Hz using an automated 3D motion capture system (CODAmotion, Charnwood Dynamics Ltd.,UK). Lightweight active markers were bilaterally attached to the body on Heel (Posterior Calcaneus), Ankle (Lateral Malleolus), 5th Metatarsal-phalangeal, Toe/Hallux, Lateral Knee (Femoral Epicondyle), Hip (greater trochanter), Posterior Superior Illiac Spine, Hand (3rd Metacarpo-Phalangeal Joint), Wrist (Ulnar Styloid Process), Elbow (Lateral Humeral Epicondyle), Shoulder (Lateral Acromion Process), Head (Temple).Third order low pass butter filter with cut off frequency 14Hz was applied to marker data, and centre of mass (CoM) was calculated (Tisserand, Robert, Dumas, & Cheze, 2016). MSE was estimated from the time series of the ankle, knee and hip angular displacement in sagittal plane and CoM position in the Z direction for two minutes of data. For MSE estimation, firstly [$y^{(\tau)}$] (coarse-grained) time series of the z direction of time series was calculated from Eq.(1):

$$y_j^{(\tau)} = \frac{1}{\tau} \sum_{i=(j-1)\tau+1}^{j\tau} x_i, \ \ 1 \le j \le \frac{N}{\tau} \quad \textbf{(1)}$$

Where τ is the timescale of interest, y_j is a data point in the newly constructed time series, x_i is a data point in the original time series and N is the length of the original time series. Then, SE was estimated on each coarse-grained time series with r = 0.15, number of scales = 1-6, and m = 2 (Costa, Peng, Goldberger, & Hausdorff, 2003). The tolerance window was calculated as r times the standard deviation of the original time series. Finally, the SE was plotted as a function of scale. The area below the SE vs. time scale curve was calculated as the complexity index (CI) which is the MSE (Eq. 2) (Busa & van Emmerik, 2016; Yentes & Raffalt, 2021):

$$CI = \sum_{i=1}^{n} S_E(i) \quad \textbf{(2)}$$

where S_E is the SE value at time scale i and n is the total number of time scales used to calculate CI.

To visualize comparison of MSE values in ankle, knee and hip angular displacement, and CoM position, younger and older groups, and their estimated central tendency, boxplots were used. Lower or higher MSE refers to lower or higher complexity, respectively. The Kolmogorov-Smirnov test was used to verify the normality of the data distribution. Since the data had a normal distribution, independent sample t-test with minimum level of significance 5% were used to compare MSE in younger and older participants in three different positions. All the calculations were done in Matlab (R2021a).

RESULTS: There was no significant difference in MSE between groups in CoM position (younger: 0.83 ± 0.14, older: 0.74 ± 0.25, p-value = 0.33), ankle angle (younger: 1.59 ± 0.28, older: 1.49 ± 0.19, p-value = 0.16) and knee angle (younger: 1.75 ± 0.11, older: 1.67 ± 0.12,

p-value = 0.19) . However, there was a significant difference in MSE between groups for hip angle (younger: 2.26 ± 0.38, older: 1.77 ± 0.22, p-value = 0.003). Generally, mean value in all different variables was higher for younger participants compared to the older participants.
Figure 1. shows box plot of MSE in CoM position, ankle, knee and hip angular displacement. Hip angular displacement had higher MSE in comparison to other positions. CoM had lower MSE in comparison to other positions (Figure 1).

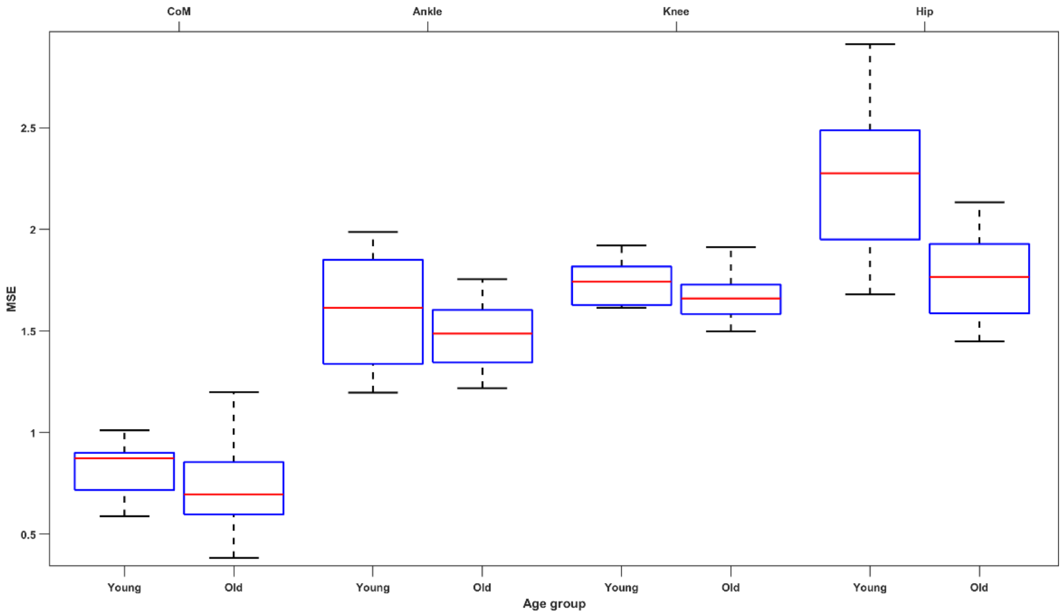

Figure 1: Multiscale entropy (MSE) values in CoM position and Ankle, Knee, and Hip angle in younger and older participants.

DISCUSSION: Age effects on gait provide important information about changes in biomechanics and motor control. Despite the high number of approaches for assessing effects of ageing on gait, only a limited number have explored changes in complexity of gait with ageing (Costa et al., 2003). The primary aim of this study was to assess the differences in gait complexity between younger and older participants using multiscale entropy computation. The secondary aim was to consider if different kinematic variables showed the same changes in complexity with age. MSE estimation in hip angle captured the effects of ageing on gait; however, CoM position, ankle and knee angle had no significant difference between older and younger populations.
MSE was lower in CoM positional data, which means CoM showed lower complexity compared to the ankle, knee and hip angular displacement. In general CoM has lower movement than the joint angles since it is a global descriptor of the system motion. Previous research has provided MSE values of CoM motion in the range of XYZ, which are lower/higher than those reported here and are consistently lower/higher than MSE values reported for joint angles, such as those reported by XYZ… MSE was higher in hip position, which is in line with expectations that the hip joint would have more complex movements than the other ankle, knee and CoM position (McCamley, Denton, Arnold, Raffalt, & Yentes, 2018).
The MSE was significantly lower in older adults compared to the younger adults in the hip angular displacement. This indicated that with ageing, aspects of the gait cycle became less complex, and more regular. The lower complexity means there is lower adaptability. Previous research has shown different values of MSE for these variables, suggesting that different study designs and participant numbers may further influence results (Yentes & Raffalt, 2021).
For MSE estimation, four input parameters (N, m, r, time scale) are needed (Costa et al., 2003). Inconsistency between studies has led to varying results, making data comparison and interpretation challenging. In this study, r and m values were fixed between populations to allow for comparison, as changing these parameters can affect the outcomes of the calculation (Pincus, 1991).

One of the limitations of this study was using fixed speed for all participants instead of preferred speed. This has been shown to alter gait kinematics and complexity of gait characteristics (Sloot, Van der Krogt, & Harlaar, 2014). The other limitation was that the selection of r, m, N, time scales is still difficult to ascertain in an objective manner.
Methodological considerations presented in this paper, which focused on gait and ageing, also have implications for sports scientists. They can apply similar techniques to understand changes in complexity of the human body with respect to motor learning, performance enhancement and risk of injury research.

CONCLUSION: MSE of the hip joint position was significantly lower for the older group as compared to the younger group but it did not differ for the ankle, knee and CoM motion. Based on the hip angular displacement, there is a loss of complexity in gait with ageing. However, loss of complexity may only be observed for some kinematic variables, which is a key point to consider for future work applying these techniques. Also, it is not possible to compare results across studies, because the variety of variables analysed and input selection for MSE calculation may lead to different results. More research is needed to determine a protocol of MSE input variable selection.

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